

[0001] OPTICAL ASSEMBLY TO BE MOUNTED ON A MICROSCOPE FOR MEASURING PERIODIC MOVEMENTS OF A MICROSTRUCTURE

[0002] The invention relates to an optical assembly to be mounted on a microscope for measuring periodic movements of a microstructure.

[0003] In particular, miniaturized components in microsystem technology require special measurement systems if the movements and degrees of freedom of the individual elements of the microsystem are to be examined and measured. For the most part, a microscope and an electronic camera are indispensable for this purpose.

[0004] For component movements and degrees of freedom perpendicular to the object plane of the microscope, the interferometric measurement method using a scanning vibrometer has proven to be advantageous. Corresponding to the wavelengths of the light used in this method, very small movements of the miniaturized components can be measured.

[0005] Movements of the components in the object plane of the microscope, such as the rotation of a micro-gear, require a different measurement method. For this purpose, typically a microscope with a mounted, electronic camera is used, which produces a series of images representing the movement so that the movement can be evaluated electronically. However, the special problem for microstructures is that the movements of the components are generally much quicker (at frequencies up to 100 MHz) than the smallest time window needed by the camera in order to be able to record an image. To solve this problem, a special microscope is used, which is provided with a stroboscope lamp. The stroboscope lamp transmits light pulses at a pulse frequency that corresponds to an excitation frequency, which simultaneously excites the component to be measured into periodic movements. Every light pulse of the stroboscope lamp thus always strikes the component at the same phase position

of the periodic movement, so that the electronic camera records an image, which corresponds to a stroboscope pulse, but which is actually combined from several integrated stroboscope pulses. Through an opposite shift of the phase position of the stroboscope pulses and the excitation frequency for the movement of the component to be measured, the next image of the movement sequence can then be recorded by the electronic camera. As a result, this produces image data that represents the movement sequence of the component to be measured.

[0006] While scanning vibrometers are already available, which can be mounted on the standardized camera mount (C-mount) of a commercially available microscope and which thus enable the measurement of movements of the micro-structures perpendicular to the object plane in a very simple way, for stroboscopic measurement of the movements of the component in the object plane, a special microscope with a stroboscopic lamp is needed.

[0007] **SUMMARY OF THE INVENTION**

[0008] For the most part, microscopes are already available in appropriate laboratories. The invention is based on the object of enabling stroboscopic detection of the movement of microstructures in the object plane of the microscope used for measurement without the use of a specially configured microscope and without requiring modifications to a standard microscope.

[0009] This object is realized by an optical assembly which includes a lower field lens and an upper field lens, with an imaging lens system arranged between the two field lenses in their beam path. A beam splitter is arranged between the two field lenses for coupling light pulses of a stroboscope lamp into the beam path. The optical assembly in the region of the lower field lens is adapted to be mounted on a camera mount of the microscope. The field lens and the imaging lens system are dimensioned and arranged so that the first object image at the camera mount of the microscope is imaged from below the lower field lens to above the upper field lens onto a second object image, and the optical assembly in the region of the upper field lens is configured correspondingly for the mounting of a camera or the like to the camera mount of the microscope.

[0010] Advantageous refinements of the optical assembly according to the invention are set forth in the Claims.

[0011] The invention thus provides an optical assembly, which can be mounted on the camera mount of the microscope and which has, in turn, a correspondingly formed camera mount on the other side. Simultaneously, this optical assembly includes a lower field lens and an upper field lens, as well as an imaging lens system arranged between these two field lenses. These optical components are dimensioned and arranged so that the first object image at the camera mount of the microscope is imaged from below the lower field lens at the imaging scale of 1:1 onto a second object image above the upper field lens and thus at the upper mount for a camera. Therefore, the optical assembly according to the invention is a kind of intermediate piece, which can very simply shift the object image to be recorded by an electronic camera farther upwards.

[0012] At the same time, and this produces the great advantage of the invention relative to previous, typically specially configured microscopes, the optical assembly according to the invention includes in its beam path between the two field lenses a beam splitter for coupling light pulses of a stroboscope lamp. Based on the invention, it is also possible for the first time to perform stroboscopic measurements for detecting microstructure movements with a commercially available, standardized microscope without special modifications to this microscope. This is because in all cases, such microscopes are provided with a standardized C-mount for mounting a camera. The adapter according to the invention thus shifts the interface for attaching an electronic camera upwards and enables light pulses of a stroboscopic lamp to be coupled in the stretch of the beam path obtained in this way without requiring any modifications to the microscope itself. Nevertheless, the full functionality of the microscope is given, because a (standardized) camera mount is also provided after the mounting of the optical assembly according to the invention and can be used both for an electronic camera and also for a scanning vibrometer or the like.

[0013] Special advantages result when the field lenses and the imaging lens system are dimensioned and arranged so that the individual rays of the beam from each image point of the first object image emerge from the second object image imaged above the upper field lens at the same angles as from the first object image. This enables a cascade arrangement for the system and two or even more optical assemblies according to the invention can be connected one after the other. However, even without this cascade arrangement, such a refinement of the invention is advantageous because all other devices, which likewise couple light into the beam path, can be used with the same alignments as if they were mounted directly on the microscope.

[0014] Preferably, the beam splitter provided in the optical assembly according to the invention is dimensioned and arranged so that the light pulses of the stroboscope lamp are coupled into the incident beam path of the microscope according to the rules of Köhler illumination. According to these rules of illumination, the individual beams diverging from one point of the light source are always incident on the object plane in parallel, so that a very uniform illumination of the object field itself is produced if the light source emits non-uniformly in the plane.

[0015] Preferably, the stroboscope lamp itself is part of the optical assembly. This then produces a fixed spatial arrangement of the stroboscope lamp relative to the beam splitter. Thus there is no need for any alignment for coupling the stroboscope light via the beam splitter into the incident beam path of the microscope.

[0016] The stroboscope lamp is preferably an LED with an aperture angle  $\theta$  and with a phosphor surface of a diameter  $d$ . The aperture angle and the diameter of the phosphor surface satisfy the relationship:  $d * \theta < 0.5$ , where  $d$  is in mm and  $\theta$  is in rad. More preferably, the LED has an optical output of more than 10 mW. These initial conditions have proven to be optimal in achieving the results according to the invention.

[0017] The imaging lens system is preferably a combination system, which guarantees aberration-free imaging. Such lens systems are known.

[0018] Preferably, the optical assembly according to the invention is configured so that the first object image is imaged on the second object image without vignetting. This guarantees maximum light efficiency, imaging sharpness, and ability to form a cascade arrangement.

[0019] The solution principle according to the invention is further embodied in a modular system for measuring periodic movements of a microstructure, which has, in addition to a microscope, which is provided with a standardized camera mount, also a stroboscope lamp, an electronic camera, and a scanning vibrometer, while an optical assembly is also provided according to the invention as described above. The optical assembly can then be mounted on the camera mount of the microscope instead of the camera. Alternatively, the scanning vibrometer can be mounted on the camera mount of the microscope, while, however, it is also possible to mount the scanning vibrometer on the optical assembly. Accordingly, the electronic camera can be mounted on the camera mount of the microscope, on the optical assembly, or on the scanning vibrometer. It is understood that for this modular system, more synchronization electronics and an evaluation computer must be provided in order to be able to execute and evaluate the stroboscopic examination.

[0020] **BRIEF DESCRIPTION OF THE DRAWINGS**

[0021] One embodiment of the invention is described and explained in more detail in the following with reference to the enclosed drawings. Shown are:

[0022] Figure 1 is a schematic representation of an example for an optical assembly according to the invention;

[0023] Figure 2 is a schematic representation of an example for a complete measurement system with optical assembly according to the invention;

[0024] Figure 3 is a schematic representation of an example for a modular system according to the invention;

[0025] Figure 4 is a schematic representation of the state of the art.

[0026] DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0027] Figure 1 shows the principle configuration of an optical assembly according to the invention, including a lower field lens 1, an upper field lens 2, an imaging lens system 4 in the beam path 3 of these lenses, and a beam splitter 5 for coupling the light pulses of a stroboscope lamp 6 into the microscope beam path. As shown by Figure 1, a first object image 7 is imaged above the upper field lens 2 on a second object image 8 by the optical assembly according to the invention. The exceptional feature of the embodiment described here is that the individual rays of the beam from each image point of the first object image 7 emerge from the second object image 8 at the same angles  $\theta$ ,  $\varphi$  as from the first object image 7 itself. According to this embodiment, the imaging lens system 4 is an aberration-corrected lens system for 1:1 imaging.

[0028] In a similar schematic representation, Figure 2 shows how the optical assembly according to the invention interacts with the other components of the measurement device. In the region of the lower field lens 1, the first object image 7 is indicated, which represents an object 9 through a microscope objective 10 and a tube lens 11 of the microscope. Now, the optical assembly according to the invention, consisting of the lower field lens 1, the upper field lens 2, the imaging lens system 4, and also the beam splitter 5, and a fixed, installed stroboscope lamp 6, "shifts" the first object image 7 into a higher plane at the second object image 8 above the upper field lens 2. This second object image 8 is detected by an electronic camera 12 on a standardized mount (C-mount) and thus can be evaluated electronically.

[0029] Figure 3 shows a modular system with the described optical assembly according to the invention, with a lower field lens 1, an upper field lens 2, an imaging lens system 4, a beam splitter 5, and a stroboscope lamp 6. The commercially available microscope, here just the microscope objective 10 and the tube lens 11 are illustrated, images the object 9 on the first object image 7. Also, the camera mount position above the upper field lens 2, on which a second object image is now projected by the invention, is provided with a standardized camera mount, so that

here a scanning vibrometer 13 and then on this device an electronic camera 12 are mounted.

[0030] Finally, Figure 4 shows a configuration according to the state of the art. Here, it can be seen clearly that the light of the stroboscope lamp 6 is coupled between the microscope objective 10 and the tube lens 11 by means of a beam splitter 5. This requires a fixed alignment and attachment of the stroboscope lamp 6 to the microscope, which is an expensive, special processing step, because the illumination mounts are specific to the manufacturer.

[0031] List of Reference Numbers

- 1 Field lens (lower)
- 2 Field lens (upper)
- 3 Beam path
- 4 Imaging lens system
- 5 Beam splitter
- 6 Stroboscope lamp
- 7 Object image (first)
- 8 Object image (second)
- 9 Object
- 10 Microscope objective
- 11 Tube lens
- 12 Camera
- 13 Scanning vibrometer